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ABSTRACT

Information overload has become a critical challenge within military Command and Control. However, the problem is not so much one of too much information but of abundant information that is poorly organised and poorly represented. In addition, the capabilities to test the effects of decisions before they are implemented and to monitor the progress of events after a decision is implemented are primitive. A virtual information-action workspace could be designed to resolve these issues. The design of such a space would require a detailed understanding of the specific information needed to support decision-making in Command and Control. That information can be obtained with the use of knowledge acquisition and knowledge representation tools from the field of applied cognitive psychology. In addition, it will be necessary to integrate forms for perception and action into a virtual space that will support access to the information and that will provide means for testing and implementing decisions. This paper presents a rationale for a virtual information-action workspace and outlines an approach to its design.

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Executive Summary

Information overload has become a critical challenge within military Command and Control. However, the problem is not so much one of too much information but of abundant information that is poorly organised and poorly represented. In addition, the capabilities to test the effects of decisions before they are implemented and to monitor the progress of events after a decision is implemented are primitive. A virtual information-action workspace could be designed to resolve these issues. The design of such a space would require a detailed understanding of the specific information needed to support decision-making in Command and Control. That information can be obtained with the use of knowledge acquisition and knowledge representation tools from the field of applied cognitive psychology. In addition, it will be necessary to integrate forms for perception and action into a virtual space that will support access to the information and that will provide means for testing and implementing decisions. This paper presents a rationale for a virtual information-action workspace and outlines an approach to its design.

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1. Information and Action

Information management has emerged as a significant contemporary challenge in modern warfare. Remarkable technological advances in communication systems and digital computation have transformed the potential use of information in military conflict. The advantage now goes not to those with the more potent weaponry but to those with the more effective information system. A commander can access a huge amount of information. Where that information is about current status and progress of events it becomes available with unprecedented speed. Nevertheless, this information is poorly organised. It is available from diverse sources and in fragments, which leaves a commander with the challenge of searching the information space to find, distinguish, summarise, integrate and understand the meaningful elements that can make a difference throughout the execution of a battle plan. That is both an onerous and a difficult task. In a high-tempo, high-stress environment it will often be an impossible one.

1.1 In the *Bubble*

The Command Decision Center of a US Naval Battle Group offers an example of an information space for support of military operations. It serves as the focal point for assembly, integration, and interpretation of information about air, surface, and subsurface activity of allied, hostile, and neutral craft. Typically that information is processed by one skilled individual, the Tactical Operations Officer, who establishes what might be termed a *mental picture* of these activities. The task is one of assimilating information from a variety of sources, of assembling an awareness of spatial and temporal relationships in the battle space, and of assessing the status of threats and also the status of defences that might counter those threats. During the time that the Tactical Operations Officer has successfully established the mental picture of these events he is said to be *in the bubble* (Roberts & Rousseau, 1989).

Bubble formation for command decisions is not accorded a central role in some of the newer ships of the US Navy. It seems that technologically sophisticated displays have been designed to eliminate the need for this skill. Nevertheless, Rochlin (1991) suggests that this has contributed to a decline in combat readiness. He argues that de-emphasis on bubble formation in the Combat Decision Center of the USS Vincennes contributed, on July 3, 1988, to the inadvertent destruction of the commercial air liner, Iran Flight 655. In contrast, the captain of a companion vessel, the USS Sides, quickly returned his attention to ongoing surface operations after he decided, with the aid of much less sophisticated technology, that Iran Flight 655 did not represent a threat.

The intuition surrounding the notion of being *in the bubble* corresponds closely with the similarly intuitive concept of situational awareness (Sarter & Woods, 1991). Both might be viewed as informal terms for *the comprehensive apprehension of information in support*

of decisions. Some characteristics of being in the bubble or of being situationally aware appear much like the experience of being immersed in virtual reality. Thus, a form of virtual reality, designated here as a *virtual information-action workspace*, might be developed to display information in a manner that would mimic the bubble experience.

1.2 Information for Modern Warfare

Information may be assembled for purposes other than real-time Command and Control. It may be employed in the service of political, tactical or strategic operations and it may be needed for long- or short-term planning, for real-time operations, or for after-action reviews. Additionally, all of these various uses may be combined in different proportions. Rasmussen (1998) has outlined the knowledge requirements of different information workspaces for those who make decisions at the national, theatre-of-engagement, active-force, mission (Figure 1) and platform levels. In this paper we illustrate an approach to designing a virtual information-action workspace by reference to Command and Control at the mission level.

Information has always been central to successful military operations but in the modern military, the role of information is increasing in importance. It has become available in different forms, at different levels of abstraction and from multiple and diverse sources. Where information was once meagre, imprecise, and ambiguous, it is now generally of high quality. However, military commanders can be assailed by such a mass of information that the significance of important pieces of it may not be apparent and the meaning of critical information can be lost.

Successful action is rarely based on a mass of information. It typically results from decisions in response to key pieces of information that become available at the right time. A timely decision based on a few key observations can turn a potential disaster into a victory. However, to achieve victory, decision-makers must be able to recognise and to act on the opportunities available to them. That requires a well designed Command and Control centre, or what might alternatively be termed an information-action workspace.

	Mission: Suppression of Enemy Air Defences
Goals & Purposes	Disrupt/destroy enemy air defences Respect international conventions Protect Air Force personnel and civil population
Priority Measures	Probability of success/loss/fratricide Reduction of enemy air defence capability (pre-identified targets, targets of opportunity) Threat priority list from: • Enemy air defence order of battle, its system capabilities • Flight profiles and defensive capabilities of projected friendly aircraft
General Functions	Detection & identification of threats, confirmation of their identity Mission planning Classification of targets (mobility, accuracy, effectiveness) Coordination with air/surface support Development of intelligence requirements Support for component commanders in developing planning priorities Allocation of assets for SEAD operations Direction & control of operations, monitoring of SEAD activities Active operations: attack, destruction, disruption
Physical Processes	Functional characteristics of sensors: • Intelligence Collection (AN/APG-70, Lantirn, Pave Tack, PDF (ELINT) • Threat detection and identification (AN/APG-70, Lantirn, ESM)
Inventory Configuration Topography	Topography, Physical configuration, Material form Map of theatre territory with location and type of resources, pictures, video Vehicle types, equipment, types and numbers Weapon types, Sensor types, vehicle types

Figure 1. Functional problem space (i.e. an Abstraction Hierarchy) for Suppression of Enemy Air Defences (SEAD), adapted from Rasmussen (1998). Note that labels for the levels of abstraction differ slightly from those used in Figure 2. The original labels used by Rasmussen (1998) are retained for this figure to illustrate that different labels may be desirable in different contexts.

1.3 A Virtual Information-Action Workspace

A virtual information-action workspace is essentially a computer interface that presents information and provides possibilities for action in a manner analogous to a mental bubble. The intuition behind the argument developed here is that this virtual space will correspond in its design to natural information-action workspaces that support robust and effective performance. As in a natural space, the information will be organised at different levels of abstraction and detail. Furthermore, it will be summarised and represented in forms that can be directly associated with functional action. A virtual space must not only clarify the relevance of available information but must also support the evaluation, implementation and monitoring of courses of action. Thus, an information-action workspace should offer action-relevant summaries of information and also capabilities to test and to implement decisions and then to monitor the course of events flowing from those decisions.

Information should be organised in such a manner that a commander could scan the information space to locate and then interpret information relevant to the current issue. This might be done in much the same sense that a carpenter might scan his workspace to identify the right tool (ie, the right capability) to satisfy an immediate need. Information should therefore be integrated, summarised and represented in forms that show its relevance to various goals. Unlike a carpenter's workshop, the properties within a virtual information space may be represented as relational and abstract properties rather than physical features. For example, an abstract property such as the threat an enemy aircraft poses to a particular allied asset is of more significance than its physical properties of location, weapons load or speed. In a natural workspace, the skilled observer has learned to recognise the functional abstract properties from the perceptible physical properties. Thus, a process of analysing and integrating more primitive properties can reveal functional properties such as threat, imminence, vulnerability, and capacity. In an information space those abstract properties might be represented directly.

2. Developing a Virtual Information-Action Workspace

The development of an effective information space requires an understanding of what to represent, how to represent it, and how to organise it. That requires a deep understanding of what information is required and what must be done. Typically, information will need to be represented at different levels of abstraction and it should be on display so that it may be scanned rather than accessed. Tools available within applied cognitive psychology (Cognitive Work Analysis, Cognitive Task Analysis) are available to identify the essential information properties (Rasmussen, Petjersen & Goodstein, 1994; Seamster, Redding, & Kaempf, 1997; Vicente, 1999). Lintern and

Naikar (2001) have outlined the manner in which these tools might be used for this purpose.

2.1 Tools for decision support

One of the concerns with implementing action is that events may not unfold as expected. There may be hidden complexities that the commander's analysis has ignored. In critical, high-tempo situations, a decision-maker will often mentally simulate the events that should follow implementation of a decision (Klein & Calderwood, 1991). If the simulation suggests a favourable outcome the decision-maker will proceed but if not, will consider an alternative. In a virtual information-action workspace, a commander could be given modelling tools to test decision outcomes. The models that lie behind those tools must provide valid predictions if they are to be of value and the tools themselves will need to be at hand so that they can be readily implemented. The design of usable and valid modelling tools poses a serious challenge but the resolution of that challenge could have considerable pay-off.

As suggested by accounts of naturalistic decision-making, experienced commanders continue to monitor progress of a situation after they have implemented a decision. They have expectations about how a situation should unfold, are sensitive to discrepancies in relation to their expectations, and remain ready to adapt their action in the face of unfulfilled expectations or changing circumstances (Klein, 1989*a*). There are, however, contrasting opinions on this point. Some argue that even experienced decision-makers can become fixated on a solution so that they fail to recognise contra-indications (Senders & Moray, 1991). This observation has become embedded in the Human Factors literature as confirmation or expectancy bias (Wickens & Hollands, 2000).

The incident discussed earlier in this paper in which the USS Vincennes destroyed an Iranian commercial airliner has been viewed as one in which confirmation bias played a significant role (Nisbett, 1988; Slovic, 1988). Klein (1989*b*) has noted that the view of a decision maker being prone to such errors as confirmation bias is based on an analytic model in which a course of action is selected after probabilities and values of different potential outcomes are evaluated. In Klein's view, this sort of decision making is rarely possible, and in natural, high-tempo, ill-structured contexts, it can lead to paralysis. The analytic model fails to take account of the important strengths of experienced decision makers who often perform well in situations where analytic procedures are impractical.

Klein argues that the captain of the USS Vincennes, given the priorities and the information at hand, could not have justified any course of action other than the one he chose. As is consistent with the concerns expressed by Rochlin (1991), Klein further argues that an inadequate display was a key precipitating factor in this incident. Crew

members searched for disconfirming evidence but, although it was available, failed to find it because it was poorly organised.

Military Command and Control typically involves high-stress, high-tempo situations in which real-time decisions play a significant role. Problems can arise either if the original assessment was incorrect or if changing circumstances change the nature of the necessary action. Thus an information-action workspace will need to display the progress of events leading from decisions in a way that permits a commander to recognise deviations and then adapt to them. That information needs to be precise and unambiguous; it needs to specify the nature of the problem and also the way in which the problem may be corrected.

The development of an information-action workspace involves two major design activities:

- Identification of the information and action needed at the interface, and
- Design of the form and layout of the space.

The first of these is accomplished by the use of knowledge acquisition and knowledge representation tools and the second is largely a matter of developing and organizing the appropriate forms for perception and action.

2.2 Knowledge Acquisition and Knowledge Representation

The essential elements for the design of a virtual information-action workspace for Command and Control are:

- Analysis of the functional requirements, including an analysis of functional purposes of Command and Control and the available resources (Figure 2).
- Analysis of information requirements and information flows.
- Analysis of strategies for working with information, for making and implementing decisions, and for monitoring events that flow from decisions.
- Development of an information-action workspace; the perceptual forms to represent the information, the action resources to implement decisions, and the spatial layout and integration of perceptual forms and action resources.

In addition, it may be useful to:

- Analyse coordination patterns between participants.
- Analyse individual cognitive requirements for participants.

A systematic process for developing an information-action workspace, including the analytic tools and knowledge acquisition strategies is outlined in more detail by Lintern and Naikar (2001).

2.3 Forms of Perception and Action

Considerable work has been undertaken in human factors and experimental psychology on evaluation of displays and perceptual forms. However, that work is of limited value in the design of a virtual information space because it has been driven by consideration of independent physical processes and not generally by the problems of displaying high-level abstractions or of integrating a complex set of interacting features. Rasmussen (1998) has outlined a typology of graphic display formats (library of perceptual forms) for representation of states, relationships and constraints at different levels of abstraction (Figure 3). To complete the design of a virtual information space, forms such as those must be assembled in a topographic space that presents critical information in a manner that supports rapid and effective decision-making.

An information space requires navigation from the highest to the lowest levels of the hierarchical information structure in an effortless and seamless manner, much as in many natural activities. The design of a flight engineer's station for a C130 aircraft by Dinadis & Vicente (1999) shows one possible way of doing this and the design of a public library interface by Pejtersen (1992) shows another. Dinadis & Vicente (1999) developed an information space based on a single-window, multi-panel format in which functions at higher levels of abstraction are allocated to different panels and details of physical form can be brought into a dedicated panel by interrogation of functions at higher levels of abstraction. Pejtersen (1992) enabled navigation through multiple windows dedicated to different levels of abstraction and different elements of the information space with a navigation tool bar. Nevertheless, the design of support for navigation through a complex and time-critical information space remains as a serious challenge.

3. Concluding Remarks

Information management has emerged as a significant challenge for our modern, technological society. Lintern and Naikar (2001) argue for the development of a virtual information-action workspace as a generic solution to this challenge. They outline the strategy for developing a virtual workspace for a distributed work domain in which the primary work is to make decisions in response to complex and diverse information. Military decision-making poses particularly significant issues for information management because of its high-tempo, high-stress demands and because decisions can have immediate and serious consequences. The conduct of future warfare will depend heavily on the effective management of information. A well-designed information-action workspace can be expected to play a significant role in the execution of modern military strategy and tactics.

Functional Purposes	High-level purposes of the information-action workspace
Priorities and Values	Priorities and values to be optimised
General Functions	Meaning as derived from functions performed on information (eg summarise, integrate, compare)
Physical Functions	Information gleaned from documents
Physical Form	Objects and properties of objects that offer information, generally documents

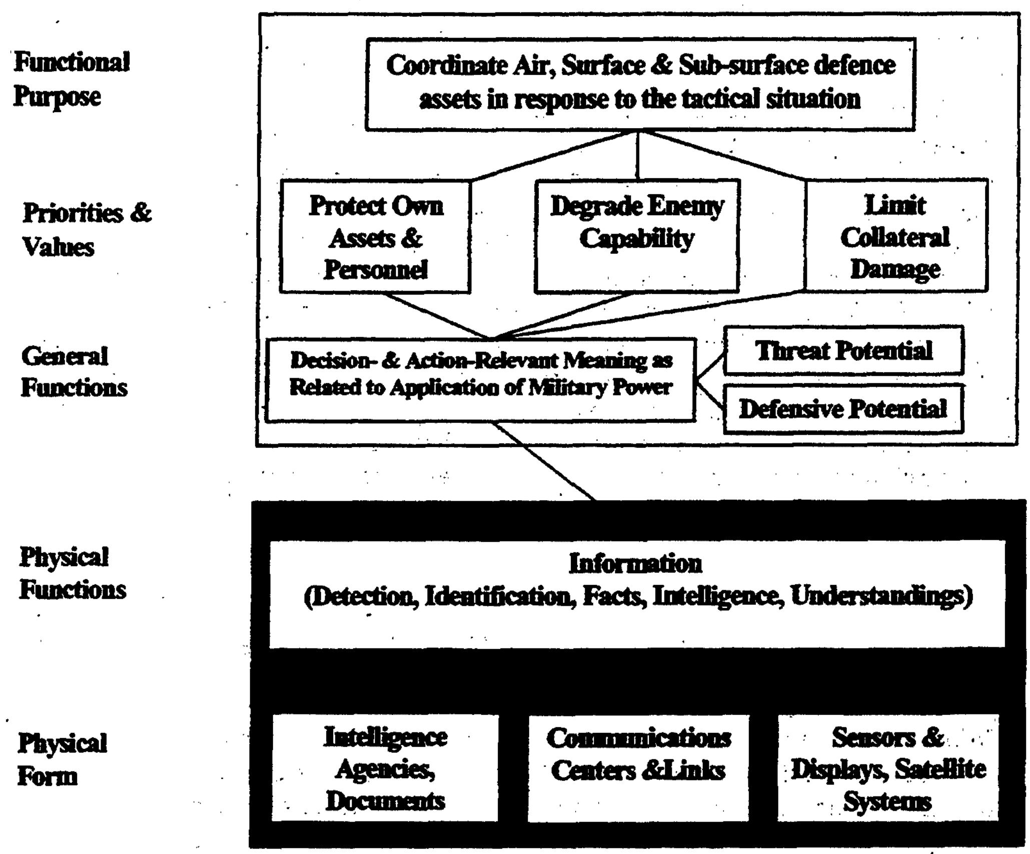

Figure 2. A fragment of an abstraction hierarchy of an information-action work domain for military Command and Control. Means-end links between functional levels are shown. Intentional properties are represented in the upper panel and physical properties are represented in the lower panel. A whole-part decomposition is shown at the level of General Function.

<table>
<tr><th>Level of Abstraction</th><th>Representation Requirements</th><th>Formats</th></tr>
<tr><td>Functional Purposes</td><td></td><td></td></tr>
<tr><td>Priorities and Values</td><td>Flow
Mass
Value
Balance
Accumulation
Dispersion</td><td>Configural Displays of Balances & Relationships between Functions & States

Limit Envelopes</td></tr>
<tr><td>General Functions</td><td>Relations
Intended States
Trajectories
Offensive Capability
Defensive Capability</td><td rowspan="2">Configural Displays
Constraint Boundaries
Threat & Lethality Shadows
Guides
Predictor Elements & Envelopes
Symbolic Diagrams
Target Lists
Priority Indicators</td></tr>
<tr><td>Physical Functions</td><td>Status of process variables with reference to target states and to limits of acceptable operation</td></tr>
<tr><td>Physical Form</td><td>Topography of the work system</td><td>Object Representations
Icons, Symbols, Signs
Mimic Diagrams
Pictorial Representations
Flow Maps
Ingress & Egress Routes
Locations
Fields of Action</td></tr>
</table>

Figure 3. A typology of display formats for different levels of abstraction, adapted primarily from Rasmussen (1998) but also with reference to Dinadis and Vicente (1999) and to Pejtersen (1992).

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